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Photometric Calibration of an EUV Flat Field Spectrometer at the Advanced Light Source

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Abstract

The photometric calibration of an extreme ultraviolet flat field spectrometer has been done at the Advanced Light Source at LBNL. This spectrometer is used to record spectrum for atomic physics research from highly charged ions in plasmas created in the Livermore electron beam ion traps EBIT-I and SUPEREBIT. Two calibrations were done each with a different gold-coated grating, a 1200 ℓ/mm and a 2400 ℓ/mm , that covered 75 - 300Å and 15 - 160Å, respectively. The detector for this calibration was a back thinned CCD. The relative calibration was determined for several different incident angles for both gratings. Within the scatter of the data, the calibration was roughly insensitive to the incidence angle for the range of angles investigated.

52.20.Fs, 52.25.Jm, 34.70.+c

I. INTRODUCTION

The accurately measured intensities of a set of spectral features can be used to determine the composition, charge balance, density, temperature, etc. from plasmas produced inside Z-pinches [1,2], tokamaks [3,4], astrophysical objects [5], and hohlraums irradiated by intense lasers [6–8]. Information about the plasma is determined by comparing the measured line intensities with atomic physics calculations and plasma modeling codes. In the extreme ultraviolet (EUV) spectral region, the emission includes the L-shell from mid-Z neon, silicon, argon, and iron ions and the M-shell from high-Z molybdenum and gold ions. The diagnostic utility of the EUV lines relies on both correct atomic data in the modeling codes and reliable photometric calibrations of the spectrometers used for the measurements.

The plasmas created in the Livermore electron beam ion traps EBIT-I and SUPEREBIT [9,10] are used for basic atomic physics research. We measure the emission from highly charged ions from many elements (e.g. Si, Ar, Fe, Xe, Au and U) and use their line intensities to check atomic physics modeling codes. For iron, detailed line compilations of the $\Delta n=1$ L-shell lines [11] have been done and compared with modeling from the Hebrew University Lawrence Livermore Atomic Code [12]. In other work the determination of the correct charge balance of gold has been investigated in a plasma having a temperature of 2.5 keV [13]. Träbert *et al* [14] have done detailed identifications of the $n=4 \rightarrow 4$ EUV transitions from Ni-like to Kr-like gold ions. The lack of calibration of the EUV flat field spectrometer (FFS) [15,16] has prevented the comparison of the Au line intensities with the theory to test the atomic physics modeling. Therefore, the FFS has been photometrically calibrated with the well characterized synchrotron light of the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory.

II. EUV FLAT FIELD SPECTROMETER

The FFS utilizes the grating design of Harada and Kita [17,18]. The two different gratings that are used in the spectrometer have nominal spacings of 1200 ℓ/mm and 2400 ℓ/mm and permit a wavelength coverage of 25-400 Å and 10-160 Å, respectively. The variable line spacing of the grating focuses the light onto a flat field that is nominally 237 mm from the grating center. The spectrometer has a grazing incidence geometry with an angle of incidence of 1.3° for the 2400 ℓ/mm grating and 3.0° for the 1200 ℓ/mm grating. The spectrometer design allows exchange of the grating and adjustment of the grating incidence angle.

The detector is a back thinned charge coupled device (CCD) which is liquid nitrogen cooled. The CCD is an array of 1024×1024 pixels each of which is 25 μm ×25 μm in size. The CCD is mounted on a precision translation stage allowing it to cover the entire spectral range with ~30 mm of translation. The spectrometer is high vacuum compatible and shares vacuum with the ALS during the calibration.

The typical grazing incidence spectrometer design utilizes an entrance slit that limits the spectral resolution. On EBIT-I and SUPEREBIT the electron beam which is ~60 μm in diameter acts as the slit for the FFS. The resolving power of the FFS is ~300. The electron beam also defines the incidence angle and the wavelength range at a given detector position. Since the relative position of the spectrometer varies each time it is connected to EBIT, the incidence angle is not precisely known and is not reproducible. The wavelength calibration for each experiment is done *in situ* with known calibration lines.

III. CALIBRATION AT ALS

The photometric calibration of the FFS was performed on the ALS beam line 6.3.2 during June 2001. The response of the total spectrometer was determined and not just the response of each individual component. Separate calibrations were done with the two different gratings (1200 ℓ/mm and 2400 ℓ/mm) and at several different angles of incidence.

The ALS produces broad band synchrotron light with a beam energy of 1.9 GeV and a beam current of less than 400 mA in a 20 electron bunch mode. The end station at beamline 6.3.2 is configured for observation of EUV light. The beamline consists of a series of thin foil filters (Si, Al, Be, B, C, Ti, Co, Cu and Mg) several thousand Ångstroms thick, a set of triple mirror order suppressors, and a monochromator to achieve a high spectral purity of the light. The monochromator has three separate variable line spaced plane gratings with spacings of 200 ℓ/mm , 600 ℓ/mm and 1200 ℓ/mm , and obtains a high spectral resolving power of ~ 7000 . A given wavelength is selected with the proper choice of grating, grating angle, filter and order suppressor.

The calibration of the FFS is achieved through a comparison with the ALS calibration diode, ACD. The diode is located just behind the monochromator system and measures the relative photon flux in voltage, V_{ACD} , as a function of wavelength with a given filter, order suppressor and grating. The ACD response, η_{ACD} , as a function of wavelength has been both accurately modeled and measured [19]. The FFS is mounted just behind the diode. When the ACD measures the ALS light, it blocks the view of the FFS. Since the light from the synchrotron decays over time with the beam current and the ACD and FFS cannot view the ALS light simultaneously, a third measurement is necessary to normalize the ACD and FFS signals. This can be done with a diode mounted upstream that has an independent view of the beam. Alternatively, the beam current can also be used as the normalization since the EUV synchrotron light is proportional to the beam current.

For calibration, the FFS was exposed to the light from the ALS monochromator. A sample spectrum from a calibration image is shown in Fig. 1. Each spectrum is a pixel binning of the CCD image over the measured ALS beam size in the direction perpendicular to the plane of dispersion. The ALS monochromator is scanned over a series of 10 to 15 wavelengths to produce each spectrum. The monochromator dwells at each wavelength for a typical exposure time, t_{exp} , of 10 to 20 seconds and then quickly positions to the next wavelength. For the weak lines below 40 Å the exposure time for a single line was ~ 60 seconds. The total time that the CCD sees the light from the monochromator is the dwell

time multiplied by the number of wavelengths or 2 to 5 minutes.

For each peak in the spectrum, a suitable background level is determined and subtracted. Each peak is summed to determine its total number of counts, C_{CCD} . The relative calibration $C(\lambda)$ for each wavelength is determined by:

$$C(\lambda) = \left(\frac{C_{CCD}}{B_{CCD}t_{exp}} \right) / \left(\frac{V_{ACD}\eta_{ACD}}{B_{ACD}} \right)$$

The variables B_{CCD} and B_{ACD} are the normalizations to the changing light flux from the ALS for the CCD and the ACD, respectively.

The relative calibration for the 2400 ℓ/mm grating is shown in Fig. 2 for three different angles of incidence, α_0 , $\alpha_0 + 1^\circ$ and $\alpha_0 - 1^\circ$, of light onto the grating. We estimate α_0 to be $\sim 1.8^\circ$. As previously mentioned, an exact and reproducible incidence angle is not possible with our standard mounting of the FFS on EBIT-I or SUPEREBIT. Therefore, a characterization of the relative calibration vs. the angle of incidence was done. Within the scatter of the data the calibration does not significantly depend on the angle of incidence. The best fit of the calibration to a polynomial for α_0 is

$$C(\lambda > 45\text{\AA}) = 2.6926 - 0.09729\lambda + 0.0014375\lambda^2 - 8.1712 \times 10^{-6}\lambda^3 + 1.6012 \times 10^{-8}\lambda^4$$

$$C(\lambda < 43\text{\AA}) = 10.765 - 1.5867\lambda + 0.082764\lambda^2 - 0.0017863\lambda^3 + 1.3636 \times 10^{-5}\lambda^4$$

This present calibration of 2001 is consistent with an earlier (unpublished) calibration done at the ALS in 2000 for the 2400 ℓ/mm grating.

The calibration with the 1200 ℓ/mm grating is shown in Fig. 3 for two different angles of incidence, α_0 and $\alpha_0 - 0.5^\circ$. The best fit of the calibration to a polynomial for α_0 is

$$C(\lambda > 75\text{\AA}) = 25.885 - 1.0934\lambda + 0.01814\lambda^2 - 0.00014906\lambda^3 \\ + 6.4839 \times 10^{-7}\lambda^4 - 1.4346 \times 10^{-9}\lambda^5 + 1.2745 \times 10^{-12}\lambda^6$$

As with the 2400 ℓ/mm grating, the 1200 ℓ/mm grating calibration does not significantly depend on the angle of incidence.

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FIGURES

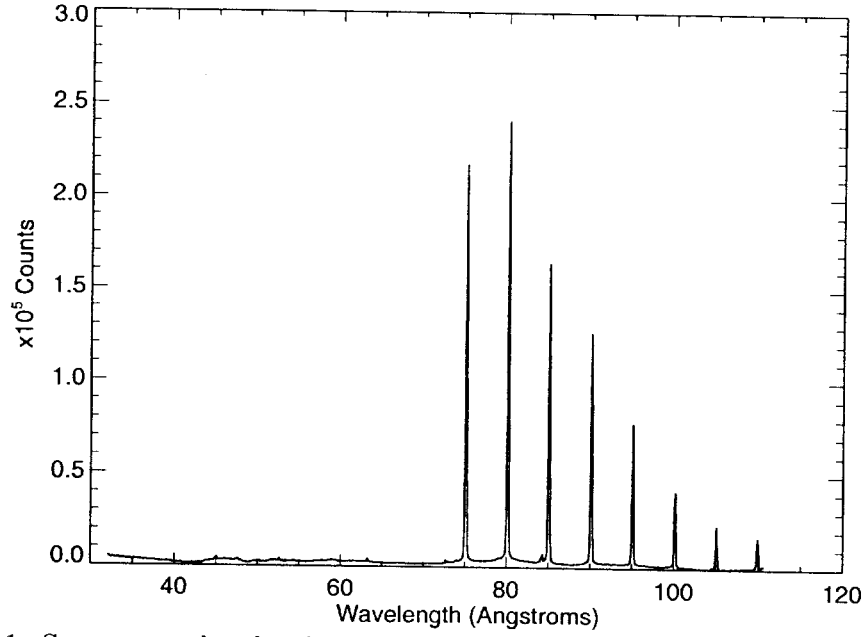


FIG. 1. Spectrum taken by the FFS with the 2400 ℓ/mm grating at the ALS.

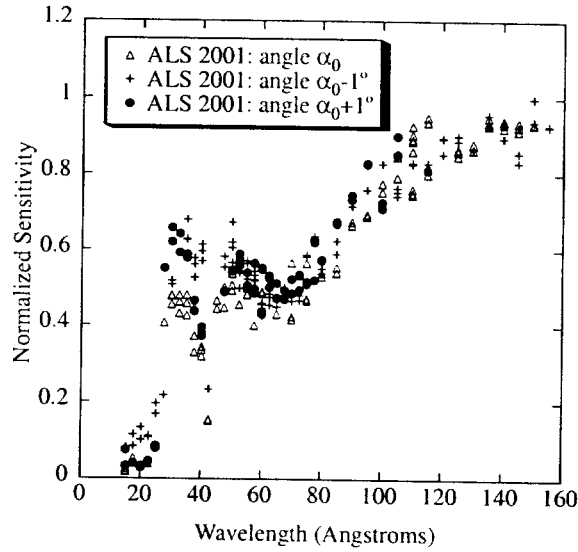


FIG. 2. Photometric calibration of the spectrometer with the 2400 ℓ/mm grating. The calibration is shown for three angles of incidence, α_0 , $\alpha_0 + 1^\circ$ and $\alpha_0 - 1^\circ$, during the measurements at the ALS in 2001.

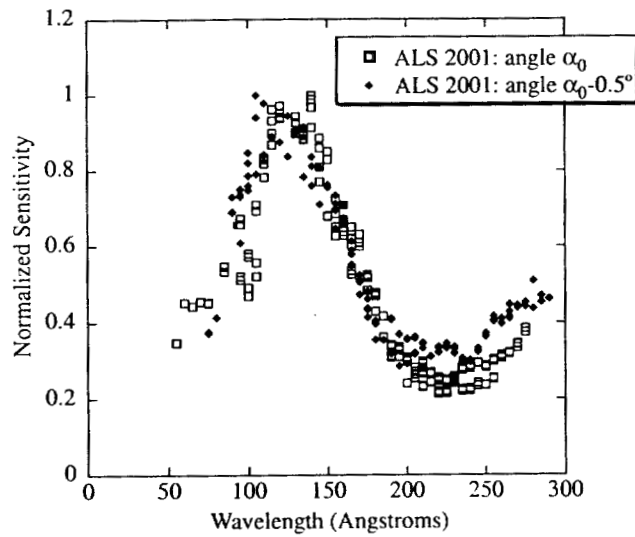


FIG. 3. Photometric calibration of the spectrometer with the 1200 ℓ/mm grating. The calibration is shown for two angles of incidence, α_0 and $\alpha_0 - 0.5^\circ$, during the measurements at the ALS in 2001.